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Assessing feeding activities of soil-living animals

I. Bait-lamina-tests

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With 3 figures

1. Prefatory note

Small, laminated baits were used to test feeding activity of soil-living animals. This method has been developed to enable everyone to monitor indefinite biotic (microbial and zootic) processes in the soil without time consuming and detailed investigations. Although approved methods for estimating decomposition rates (incl. feeding activity of soil invertebrates) are available (reviews resp. references eg in DUNGER & FIEDLER, 1989; HARRISON *et al.*, 1988; HEATH *et al.*, 1964, 1966; SEASTEDT, 1984; SZEGI, 1988) such a method is needed because a survey of spatio-temporal structuring of biogenic processes in soil areas is one of necessary premises on which a successful pedobiological sampling strategy and ecological analysis must be based.

The bait-test preliminarily described by TÖRNE (1989) is based upon visual assessment of feeding traces on small portions of thin laminated bait substrata exposed to edaphic processes in soil.

Nevertheless some procedures of the original bait-lamina-test, described in this paper, were changed and simplified in the meanwhile (TÖRNE, 1990; the following presentation of the method, problems and results may be of fundamental ecological interest.[1])

Some results (obtained from more than a thousand bait-lamina-tests) were selected to illustrate procedures and to demonstrate the suitability of such tests for screening undefined feeding activities of soil animals.

Selection of results followed a base-line of ecological problems, to which investigators of forest soils should have regard:

- changing vertical differences in biotic activities suggest a dynamic vertical stratification of soils (functional layers).
- the functional surface of plant-covered soils is dynamically impressed by changeable living conditions.
- edaphic processes are significantly influenced by plant-cover.
- due to grazing game, in open places the change of plant-cover follows changing humus-forms with a considerable delay of several years. This discrepancy causes a considerable variation of humus quality and edaphic processes under similar plant-cover.

2. Method, materials and sites

2.1. Methodology

Series of thin **bait-laminae** consisting of a mixture of pulverized substances and water (and supported by perforated plastic strips) were inserted into the soil (or individual soil layers) and thus exposed to animal feeding activity. After a given time of exposure (ranging from 4 to 120 h and depending as well on soil temperature and moisture as on intensity of animal feeding activity), positions and numbers of pierced bait-laminae on each strip were recorded. These data then furnished the parameters of estimating feeding activity in the litter and/or soil layers of interest.

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[1]) More detailed and critical information on bait-tests and on the production of the necessary tools can be obtained from the author. Information will be available in German language and will be kept up to date, for 3 years, incorporating any future practical and theoretical experience obtained by the author.

2.2. Materials and preparation of strips

Narrow strips of thin PVC plates (6 mm × 150 mm × 0.5 mm thick), with a line of 16 perforations (1.8 mm diameter) down the centre, were used to support the baits (fig. 1). The end of the strip is hooked to engage on a knife used to insert the strips into the soil. The **bait substrate** (as used for below mentioned tests only!) was made upon a gravimetric basis of 83% sieved (100 µm mesh) chernozem soil with 5% gypsum (Plaster of Paris) as a binding agent, 5% powdered bran flakes, 4.7% powdered milk, 2% peptone (peptic blood peptone) and 0.3% mannitose. The materials were mixed dry and stored as a stock medium. For use a small quantity of the medium was mixed with water

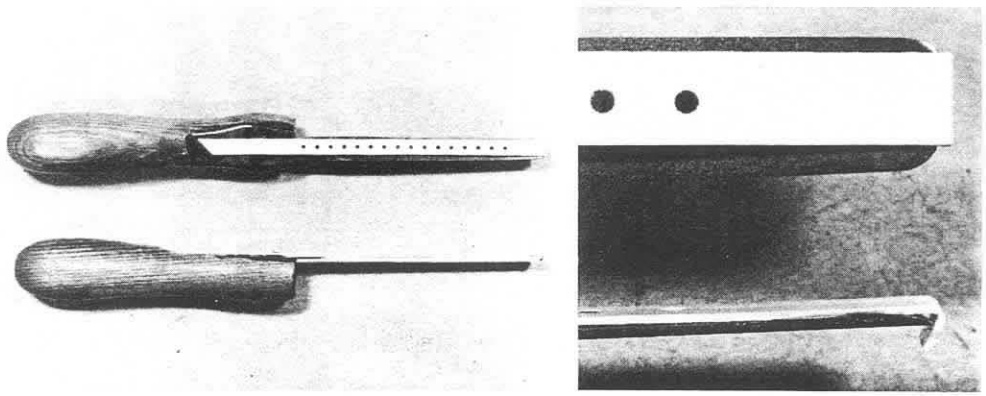

Fig. 1. Thin plastic support strips bearing a series of small holes. Perforations were furnished with threaded edges to hold the bait-laminae securely in place. The rabbeted end of the strips functioned as a catch for a special stiletto knife used to push the strips into the soil, so that the upper bait-laminae became exposed beneath the soil surface. The blade of the knife juts out to the same length as the under part of the perforated strips.

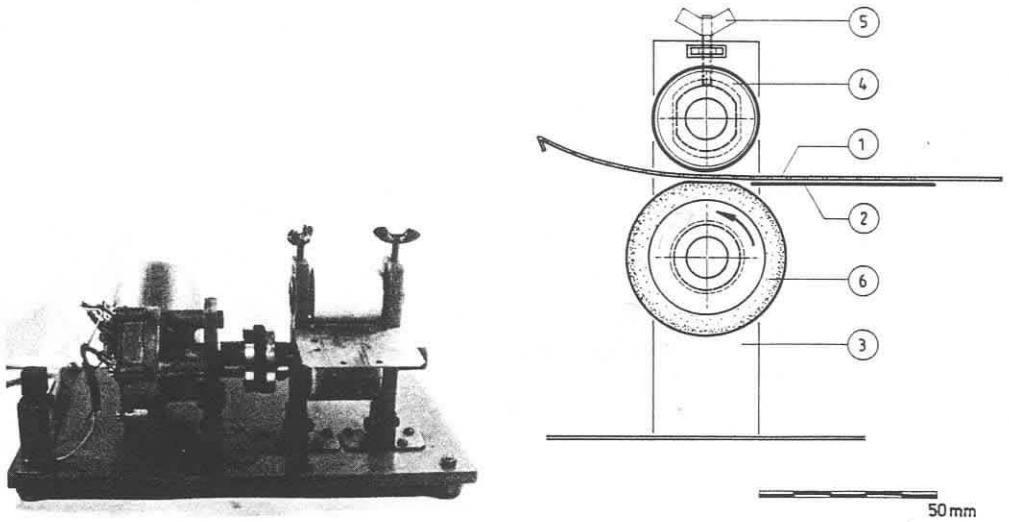

Fig. 2. Mangle-type roller for compressing bait-laminae by passing the strips between the rollers. Strips (1) must be inserted above the dish (2) with the rabbeted end uppermost. Details of construction: two cylindrical rollers are bedded one upon another in supports made of PVC (3). The upper roller (4) is made of unwettable PTFE, is spring-loaded and can be pressed down by tightening the wing-nuts (5). The lower roller (6) is covered by a gummy elastic layer, and can be continuously driven by a windshield-wiper-motor, connected by a flexible fixed clutch.

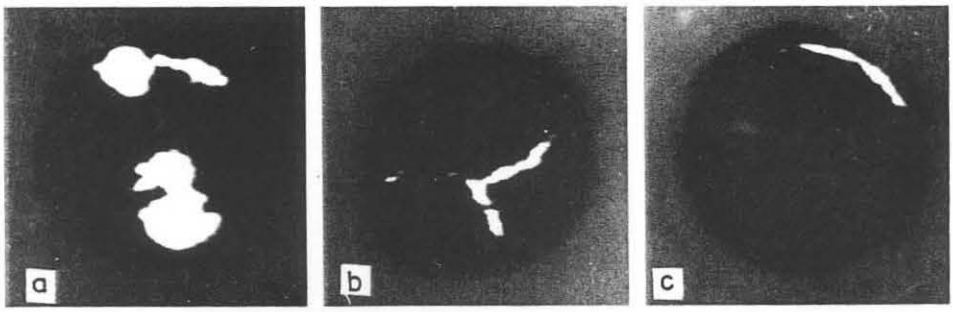

Fig. 3. Examples of scored bait-laminae: pierced by animal feeding (a), cracked by friction and/or by shrinkage (b and c).

to form a kneadable dough. The bait material was then pressed into the perforations by drawing the strips between thumb and forefinger, then further compressed by passing the strips between rollers of a mangle (the bait-laminae thereby become more resistant to damage by friction and/or erosion; see fig. 2). Complete filling of the perforations was checked on a transmitted-light screen.

2.3. Application of strips

Groups of 16 strips were inserted into the soil or the layer covering the soil either in rows or in a grid of ca. 50 cm × 50 cm. Because variations of data-items were used for statistical analysis number of strips per group were equal to the number of perforations on the strips used. Regular spacing and/or individual marking (with plastic or wooden sticks) aided recovery of the strips at the end of the test. In addition all groups were identified by numbered labels.

If possible, strips were inserted directly, but if resistance to penetration was too great, the soil (or covering layer) was first punctured with a narrow knife. Strips were pushed vertically into the soil and/or covering layer, so that the upper laminae were located just below the soil (or litter layer) surface. Replication usually consisted of 3–4 (sometimes twice as many) groups of strips per site or treatment.

Duration of exposure of baits (mentioned in this paper) ranged between 20 and 120 h. Temperatures were measured in the upper soil layer (4 cm below surface) at several points at each site before and after the tests; moisture was not measured but tests were carried out during or after rainy periods.

2.4. Sampling and examination of bait-laminae

Strips within groups were sampled and stored in partitioned bags. After rinsing them in water without any particular precautions (occasionally after several days of refrigerated storage), strips were drained vertically on a drip board and examined with low magnification (5 or 10 times) on a light screen (in numeric sequence of groups): Pierced laminae which, for each strip of a group, were recorded on a computer (initially indexed in grid format, see table 1).

As a rule, pierced laminae could be reliably distinguished from those affected by friction or shrinkage (fig. 3). Nevertheless, because of the varying consistency of soils, the rate of mechanical erosion of laminae was measured on each occasion by control tests. **Control strips** were inserted and sampled immediately (not exposed to feeding activities). The critical margin of failure was set at the level of 3% of total laminae.

Used strips were washed in an ultrasonic cleaner.[1])

2.5. Computer procedures and biometric analysis

Numbers of pierced laminae per strip (S_x) and per position on strips (S_y) were used as data-items for statistical procedures, not primary findings (binary items). Original files of data-items consisting of regular **xy-sequences** were transformed by computer procedures into special files for statistical analysis. Part-files belonging to different variants (sites, treatments or layers) were subjected to the non-parametric U-test (MANN & WHITNEY, 1947). Effects of sites or treatments were estimated on the basis of **x-data** and effect of strata on the basis of **y-data** (see table 2).

[1]) Recently we use abundant earthworm populations [*Eisenia fetida* (SAVIGNY)] to provide cleaning of strips.

Table 1. Example of derivation of two files of data items (S_x & S_y) from primary findings on 16 strips of a group, registered as binary numbers in grid format.

Chip no.	Sequence of laminae (positions 16 ↔ 01)																
	16	15	14	13	12	11	10	09	08	07	06	05	04	03	02	01	S_x
01	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
02	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
03	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
04	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	6
05	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	2
06	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	2
07	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
08	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
09	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	0	5
10	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	3
11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
12	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	6
13	1	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	9
14	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	4
15	0	0	0	0	0	0	0	0	0	1	0	1	1	1	1	0	5
16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
S_y	2	0	0	0	0	0	0	0	1	2	4	6	5	7	8	9	

Mean = 2.75; n_l = 256; n_i = 32; SD_x = 2.79; SD_y = 3.26

Test 890117/2 (T_e 48 h; $T_{i/f}$ 5.3/5.2 °C) in a pine stand on sandy soil with "moderately fresh raw humus", covered with *Avenella flexuosa* and *Pleurozium schreberi* (Forest district Liepe, Department 22). Terms for humus-forms used in this paper are literal translations of German language terms only; adjectives in these terms (e.g. "dry", "fresh" etc.) refer to pedogenetical but not to current conditions.

Note: Strips were examined from the lowest (left) to the highest (right) position of laminae on the strip. Visual observations of laminae were registered as binary numbers (1 for pierced laminae, 0 for intact laminae) in the matrix. Summed primary findings as rows of data items (S_x and S_y) were combined at their point of intersection into a xy-sequence as part (section) of a file. Occasionally x- or y-data items were separately subjected to statistical procedures. For detailed explanations see sect. 2.5 and 2.6.

Unlike the biometric analysis of original x-sections, y-sections stemming from the same variant (before biometric analysis) were split into synthetic sections.

Since in practice it was impossible to optimize and/or equalize times of strip exposure, mean rates of feeding activity were calculated in terms of 12 h exposure.

2.6. Remarks concerning presentation of results (Tables 1−5)

Files were named by initial date of the tests. **Exposure times** of strips are given in hours (h_e). Numbers of exposed bait-laminae are specified in the form of factors (number of replications per variant × number of laminae per strip or per layer within a group of strips); **numbers of bait-laminae** (n_l) or **numbers of data-items** (n_i) relate in each case to variants or sub-variants, not to the whole test ($n_l : n_i$ = 16 : 1; see sect. 2.5.). **Initial and final temperatures** (°C) of tests were always measured at several points at a depth of 4 cm below the surface (sometimes in the vegetation layer only). The means of several measurements (not of mean temperature) are generally provided in the form of fractions. Temperature measurements only served to assess prospective times of exposure, not to explain results. Especially in the case of long-term exposure, these temperature data would not yield information on thermal conditions during the test.

Mean Feeding Activity Rates (MFAR) were calculated as quotients per hundred exposed bait-laminae and for exposure times of 12 h only. In addition, for the special purpose of comparing rates per layer (from 0.5−4.0 cm and 4.5−8.0 cm below the surface), the ratio of the two layer-specific quotients from one variant is given in brackets.

In comparing data, it should be noted that symbolised distribution of pierced bait-laminae (sequences of ○) in table 2−4 are based on untransformed means of original data. It should also be noted that sums of MFAR calculated

Table 2. Vertical distribution of pierced (○) laminae on strips of 4 base-groups exposed in the litter and upper soil layer (L + Ah) of a 130 year-old beech-stand[a]).

1.	2.	3.	4.	5.	6.	7.	8.	9.
Depth (mm)	Code no. of y-sections[b])				Mean[c]) (n_i4)		MFAR (n_i32)	SD
	39	40	41	42				
05	0	0	0	0	0.00			
10	6	5	7	6	6.00	○○○○○○		
15	8	8	7	8	7.75	○○○○○○○○		
20	7	9	8	9	8.25	○○○○○○○○		
25	7	8	7	5	6.75	○○○○○○○		
30	5	4	7	3	4.75	○○○○○		
35	3	6	3	1	3.25	○○○		
40	3	2	5	1	2.75	○○○	7.94(94)	4.78
45	2	1	1	0	1.00	○		
50	0	1	2	0	0.75	○		
55	0	0	0	0	0.00			
60	0	0	0	0	0.00			
65	1	0	0	0	0.25			
70	1	0	1	0	0.50	○		
75	1	0	0	0	0.25			
80	0	1	1	1	0.75	○	.50(06)	.80

MFAR 3.53; SD 3.67; alpha 0.00

Test 881011 (n_i 64; t_e 44 h; T_{vf} 12.6/12.3 °C) in forest district Schönholz, department 61a.

[a]) Results of statistical analysis of y-data, as presented in this table, are denoted as a "feeding activity profile".

[b]) Numbers refer to the identifying code for specific y-sections of the file 881011l16h044.

[c]) Different means or MFARs (Mean Feeding Activity Rates) refer to different combinations or quantities of data items (n_i). Means in column 6 and symbols for means of pierced laminae (○) in column 7 are based on 4 data items each from 4 y-sections (39–42) in 16 different positions on the file (referring to different depths of exposure of laminae). MFARs in column 8 refer to means in different layers (0.5–4.0 cm and 4.5–8.0 cm below surface) MFAR below the table refers to the mean feeding activity rate calculated on the basis of all data items of sections 39–42. MFARs in the upper layer (with highest activities), the lower layer (with lowest) and the whole layer (0.5–8.0 cm below the surface) as relative estimations (in this case) cannot be related directly.

for layers (on the basis of y-data) will not be identical to those calculated for sampling areas (on the basis of x-data).

For estimation of the probability of error the parameters α were calculated on untransformed raw data of each file subjected to U-tests. To simplify the tables occasionally levels of significance of differences are indicated, by asterisks only; $\alpha \leqq .10$ (*); $\alpha \leqq .05$ (**); $\alpha \leqq .02$ (***); $\alpha \leqq .002$ (****); asterisks indicate significance of differences in two directions (↔).

2.7. Sites

All sites investigated belong to the Forest Management District Eberswalde. Soils originate from loose (sandy) fluvio-glacial deposits from the Pommern (Pommersche) and Frankfurt (Frankfurter) stages of glaciation of the river Weichsel, with the characteristic succession of "Moraines", "Sander" and "Talsand". The surface relief is mostly flat, only the beech wood in district 61 (Schönholz) is on weakly undulating sand dunes (more detailed informations in Anonymous, 1969).

The sites are located at 40–50 m a.s.l. in the region of Eberswalde; the long term mean annual precipitation average is 550 mm × a^{-1}, long term annual mean temperature is 8.6 °C. On the basis of phenological data, the cumulative temperature means and data on climatic water balance the forest districts mentioned below belong (according to ADLER, 1987) to the relatively warm and dry regions of meso-climate-type 2 (long term annual mean temperature 10.3 °C, climatic water balance .24 mm × d^{-1}, which indicates an imbalance between mean precipitation and mean evapotranspiration).

Table 3. Results of a statistical analysis of vertical distribution of pierced (○) laminae, exposed in the upper soil layer (L + Ah) of a 19 year-old clearing of a beech-stand, mainly overgrown with *Calamagrostis epigejos*.

A. Control, untreated plot with cover of *C. epigejos*				B. Plot with *C. e.*, cleared in spring	
Depth [mm]	SD	Mean[a]) (n_i4)	Mean number of scores	Mean (n_i4)	SD
05	0.43	6.75	○○○○○○○ ○○	1.50	1.66
10	1.48	4.75	○○○○○ ○○	2.25	1.66
15	1.48	3.25	○○○ ○	1.25	0.83
20	2.28	3.25	○○○ ○	1.00	0.71
25	1.48	3.25	○○○ ○	1.00	0.71
30	1.30	1.75	○○ ○	0.50	0.50
35	1.50	1.50	○○ ○	1.00	0.71
40	0.50	0.50	○ ○	0.75	0.83
45	0.83	0.75	○ ○	0.75	0.83
50	0.50	0.50	○ ○	0.50	0.50
55	0.50	0.50	○ ○	0.50	0.50
60	0.71	1.00	○ ○	0.50	0.50
65	0.87	0.50	○ ○	0.43	0.75
70	0.43	0.25		0.00	0.00
75	0.43	0.25		0.43	0.23
80	0.43	0.25		0.75	0.83
I.	3.95	**4.75**(89)		**1.56**(73)	1.66[b])
II.	.59	**0.59**(11)		**0.59**(27)	.80
Alpha		10^{-7}		9.5×10^{-3}	

C. Plot with *C. epigejos*, treated with PKCa				D. Plot with *C. e.*, treated with NPKCa	
Depth [mm]	SD	Mean (n_i4)	Mean number of scores	Mean (n_i4)	SD
05	2.18	4.50	○○○○○ ○○○○○○○○○○○	11.25	1.64
10	0.83	2.75	○○○ ○○○○○○○○○○	10.00	2.92
05	0.83	1.75	○○ ○○○○○○○○	8.25	2.95
20	0.50	0.50	○ ○○○○○○○	7.25	3.27
25	0.00	0.00	○○○○○○	6.00	2.55
30	0.43	0.25	○○○○	3.50	3.20
35	0.00	0.00	○○○○	3.50	2.06
40	0.50	0.50	○ ○○	2.00	1.22
45	0.50	0.50	○ ○○	1.50	1.12
50	1.12	1.50	○○ ○	1.00	0.71
55	0.50	0.50	○ ○	0.50	0.87
60	0.00	0.00	○	1.00	1.22
65	0.00	0.00	○	1.25	1.09
70	0.00	0.00	○	0.50	0.50
75	0.00	0.00	○	0.50	0.50
80	0.50	0.50	○ ○	0.75	0.83
I.	2.88	**1.88**(80)		**10.59**(90)	6.89
II.	1.05	**0.47**(20)		**1.19**(10)	1.19
Alpha		0		.0164	

Tab. 3 (continued)
Results of statistical analysis of x-files related to findings from the whole layer 0.5–8.0 cm below the surface.

	A untreated	B cleared	C PKCa	D NPKCa	Differences		
MFAR	**2.28**	**.98**	**.88**	**4.88**	D	A	B
SD	3.44	1.61	1.08	4.26	C 4.0****	1.4	0.1
					B 3.9****	1.3**	
					A 2.6****		

Statistical two-way test (↔): $\alpha \leqq 0.002$ (****); $\alpha \leqq 0.050$ (**).
Lamina-test 881011 (n_i 4 × 64; t_e 44 h; $T_{i/f}$ 12.7/12.0 °C) in the forest district Schönholz, department 61a.
Explanations of variants: Size of plots ca. 5 m^2; two replications of each variant. In early spring standing dead organic matter of plot B was cleared (ca. 2 cm above the surface) and all necromass (incl. litter) was removed.
Fertilizer treatment applied in April 1988 (elemental content of NPKCa calculated in kg per ha): 200 (N), 200 (P), 80 (K) and 5000 (Ca).
[a]) Different means refer to different combinations and different quantities (in lines I & II n_i amounts 32 each) of data items. Means within brackets are expressed as % total MFAR.
[b]) MFAR, SD and Alpha calculated on the basis of y-data-items (n_i 32; TF (12 h) = .56) related to findings from layers I & II (I = 05–40 mm below surface; II = 45–80 mm b.s.).

Table 4. Results of comparative lamina-tests in different patches of the ground vegetation of a pine stand on sandy soil (leptic podsol) with a layer of "moderate meagre raw humus".

Depth [mm]	Tests in patches with different cover					
	Cladonia rangiferina		*Pleurozium schreberi*		*Avenella flexuosa*	
05	○○○○○○		○○○		○○○○○○○○○○	
10	○○○○○○		○○○		○○○○○○○○○○	
15	○○○○		○○○		○○○○○○○○○○	
20	○○○		○○○○○		○○○○○○○○○◔	
25	○○		○○○○○○		○○○○○○○○○	
30	○○		○○○○○		○○○○○○○○○	
35	○		○○○○○○		○○○○○○○○	
40	○○	1.25(83)	○○○○○○	2.34(63)	○○○○○○○○○	5.94(67)
45	○		○○○○○○		○○○○○○○	
50	○		○○○○		○○○○○○○	
55	○○		○○○○		○○○○○○	
60	○		○○○		○○○○○	
65			○○		○○○○	
70	○		○○		○○○	
75	○		○		○○○	
80	○	.25(17)	○○○	1.38(37)	○○○	2.56(33)
		****		***		****
MFAR	**.72**		**1.92**		**4.31**	
SD	1.05		1.42		3.13	

Note: All intra- and inter-variant differences between MFARs are highly significant (percentage values of means in brackets). Data items of y-sections were used for intra-variant comparisons, data items of x-sections for inter-variant comparisons.
Test 861114 (n_i 3 × 64; t_e 120 h; $T_{i/f}$ 5.3/4.4 °C) in district Hegermühle, Dept. 141.

Table 5. Results of comparative bait-lamina-test in different patches of the ground vegetation of a mixed pine stand on sandy soil (leptic podsol) with layer of "moderlike raw humus".

File-data		Mean feeding activity rates (MFAR)			Differences between MFAR	
		Af	Af & Ce	Ce		
I. 870811	**a**	**16.3**	**18.7**	**23.9**	Af & Ce	Ce
	b	11.9	12.7	12.9		
					Af 2.4	7.7****
	c	22.8(70)	25.6(69)	32.2(67)		
		10.0(30)	11.4(31)	15.8(33)	Ce 5.3***	
		****	****	****		
			Vm & Af	Ce		
II. 870821	**a**	–	**20.2**	**19.2**	No difference	
	b	–	14.5	13.8	Alpha .382	
	c	–	30.9(77)	29.3(76)		
		–	9.3(23)	9.2(24)		
			****	****		

I. 870811; n_i 3 × 48; t_e 22 h; $T_{i/f}$ 17.2/18.3 °C.
II. 870821; n_i 2 × 48; t_e 13 h; $T_{i/f}$ 18.1/16.4 °C.
Note: Tests in forest district Liepe, department 32 at different periods and after different times of exposure (t_e). Strips were inserted either into patches covered by a single plant species [*Avenella flexuosa* (Af) or *Calamagrostis epigejos* (Ce)] or into patches each with a dominant and a subdominant plant species (*A. flexuosa* sparsely mixed with *C. epigejos* (Af & Ce) or *Vaccinium myrtillus* undergrown with *A. flexuosa* (Vm & Af)).
Data in rows indicated by letters are: (a) rates of mean feeding activity per 12 hrs; (b) standard deviation; (c) ratio of MFARs in the upper layer of 0.5–4.0 cm and 4.4–8.0 cm below the surface (percentage means within brackets). Asterisks below the ratios indicate degree of significance of intra-variant differences. Mean of temperatures, measured in humus layer (4 cm below the surface) at several points before (T_i) and after exposure (T_f).
Inter-variant differences between MFARs and their significance (calculated by analysis of x-data) are presented at the right margin of the table.
As a rule tests were carried out during rainy periods or when soils were moist.

The sites were selected for investigation with regard to the following ecological problems:

(1) The increasing occurrence of *Calamagrostis epigejos* (L.) ROTH, as a weed which competes on poor sites (and especially during dry seasons) with pines for water; it often overgrows plantations of young trees (see below, Schönholz, dept. 61 and Liepe, dept. 32).

Functional shortage of water (and encouragement of *C. epigejos*) may also be a consequence of increasing immission (input) of NO_x.

(2) Rapid change of raw humus forms (Heegermühle, dept. 141 and Liepe, dept. 32) partly as a consequence of air pollution. In addition, feeding of game retarded the adaptation of the ground-flora to the changing quality of humus-form. The metabolic processes, indicating (and/or underlying) changing humus-forms, are at present poorly understood.

The following information pertains to specific sites only, not to districts:

Schönholz, dept. 61 (tables 2–3): 144-year-old beech stand on a leptic podzol[1]) (Finowtaler Sand-Braunpodsol) and a clearing (formerly a 133-year-old mixed stand with *Pinus sylvestris* (L.) and *Fagus sylvatica* (L.) on a dystric Regosol (Schwärzer Sand-Ranker); both sandy soils; loam layers occur at a depth of 1.5–2 m.

Where the beech canopy is dense, the soil is covered only by leaf litter and where more light penetrates through the canopy, the litter layer is less thick and a sparse grass cover exists [mainly *Avenella flexuosa* (L.) PARL. and *Calamagrostis epigejos*]. The clearing (since 1970 a poor grazing place for game) is densely covered by grass, dominated by *Calamagrostis epigejos*. In 1970 the clearing was deeply ploughed and planted with *Pinus sylvestris*. But the young trees could not compete with the grasses because the humus layer remaining from the former tree stand was piled up in ridges (ca. 50 cm broad and high) and the furrows were deprived of the protecting top soil. The ridges frequently dry up and the denatured humus becomes unwettable and useless for young trees. Moreover, the competitive ability of a xerophilous ground-vegetation is apparently favoured by increasing input of NO_x and by a relatively low rate of precipitation.

[1]) Nomenclature according to LIEBEROTH, 1981.

Heegermühle, dept. 141 (table 4): ca. 80-year-old pine stand of poor quality on a deteriorated leptic podzol (Sand-Braunpodsol), covered by a sparse ground vegetation on "moderately fresh meagre raw humus" ("mäßig frischer Mager-Rohhumus")[1]). In former times the site was temporarily used for agriculture and for raking litter to bed down cattle. The main components of the ground vegetation are the grass *Avenella flexuosa*, several mosses [e.g. *Pleurozium schreberi* (WILLD.) MITT., *Leucobryum glaucum* (L.) SCHIMPER, *Hypnum cupressiforme* L., *Dicranum undulatum* (ERH.), *D. scoparium* (L.) HEDW. *etc.*] and lichens of the *Cladonia rangiferina*-group [*Cladonia rangiferina* (L.) WEB]. More detailed description has been provided by TÖRNE (1978).

Liepe, dept. 32 (table 5): ca. 100-year-old pine stand of middle quality, mixed with weak *Fagus sylvatica* L., *Quercus petraea* (MATTUSCHKA) LIEBL., growing on sandy soil (leptic podzol; Sand-Braunpodsol). A vigorous, relatively species-rich ground-flora covers a layer of "moderately fresh, raw-humus-like moder" ("mäßig frischer, rohhumusartiger Moder"). Where the tree stand becomes thin, scattered patches of ground cover are dominated by *Calamagrostis epigejos*, *Avenella flexuosa* or by *Vaccinium myrtillus* L.

3. Results and discussion

At first sight the principal conclusions is that bait-lamina-tests help, in a simple way, with the detection of functionally distinct strata within the near surface soil layers (tables 2–4).

The functional soil surface begins where plant cover forms a (furlike) damp, interstitial stratum (L_i), rich in food and suitable for activities of soil-living animals, but open to the atmosphere (tables 3 and 4)[2]).

Strips inserted into grass-covered micro-sites (e.g. table 3, test 88-10-11, plots A–D) extended above the more compact soil surface by about 10 mm. In plots A, C and D a ca. 10 mm thick litter-layer covered the mineral soil, and loose organic matter in plot B was raked off in spring after cutting the standing necromass of grass. Feeding activity in L_i of plot B (where litter-layer was removed) was extremely low, though the amount of grass in comparable plots of A and B was not visibly different. In contrast to this, feeding activity in L_i of plot D was extremely high, where standing dead organic matter was lying on the ground, probably a result of the high nitrogen supply. While L_i in plot D was relatively closed, like a L_n, the surface grass in plot C, despite having a similar amount of necromass, was relatively open.

The differences in results of tests in plots A and C cannot be adequately explained, since the amount of surface necromass obviously was lower in plot A than in plot C. Possibly treatment of plot C has had a long term suppressive effect on animal feeding activities. Feeding activity profiles (e.g. table 4) also reflect general living conditions within the layers indicated and/or caused by the mosaic of ground flora. In comparison with lichens and mosses the grass *Avenella flexuosa* (the first, and generally the only species of higher plant which settles in pine stands on raw humus) is a more demanding plant; but in comparison with *Calamagrostis epigejos* and *Vaccinium myrtillus* (at a richer site on raw-humus-like moder) it is a relatively undemanding species. MFARs in table 5 reflect shifting indicative values of these plant species. Considering interrelationships between humus form, vegetation and edaphic processes it should be recognized that changes in vegetation follow changes in humus form probably with a delay of some years (especially in open areas where game mostly suppress more demanding plant species). Therefore no definite coïncidence between humus-form, plant cover and edaphic processes can be expected.

4. Concluding and critical remarks

Because of the dynamic complexity of spatio-temporally structured and microclimatically highly affected ecosystems, only results of simultaneous investigations are comparable. As a rule different plant species and/or various elements of cover have different effects on edaphic processes

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[1]) In the literally translated terms of humus-forms adjectives like "dry", "fresh" or "moderately fresh" do not relate to the actual water content of humus but to certain conditions of humus development. The adjective "meagre" means "poor in available nutrient content".

[2]) Corresponding to definitions by BABEL (1972), the interstitial layer is defined as an open, functional, morphologically indefinite sub-horizon (L_i) of the litter layer (i for interstitial). LAVELLE & PASHANSASI (1989) refer to the same phenomenon as "the effect of physical protection of soil by vegetation cover".

but no constant and simply defined correlation between vegetation and edaphic processes is to be expected. Position and thickness of certain functional layers (incl. L_i) often vary from micro-site to micro-site and within seasons. System processes are not only influenced by current interactions of factors but also by past processes. All these circumstances make it more difficult to provide reliable quantitative estimations of biotic processes, especially feeding activities, statistically representative for areas (e.g. 100 m^2 and more).

In principle, comparative bait-tests offer a potentially time- and energy-saving method of studying edaphic processes, but more experience is needed to improve and fully assess the reliability of the technique. A methodological advance has been obtained by using strips (or orthogonal perforated sticks) sealed with a bait substrate which was dried after filling up the holes.

6. Zusammenfassung · Rezjume

[Schätzung von Freßaktivitäten bodenlebender Tiere. I. Köderlamellen-Test]

Am Beispiel ausgewählter Ergebnisse wird ein Screening-Test beschrieben, der dadurch gekennzeichnet ist, daß (schon wenige Stunden oder Tage nach Versuchsbeginn) tierische Fraßspuren an dünnschichtigen Köder-Lamellen visuell ermittelt werden. Das einfache Verfahren ist darauf ausgerichtet, mit verhältnismäßig geringem Arbeitsaufwand, auf einfache Weise und rationell, größere, statistisch auswertbare Daten-Mengen zu gewinnen.

Als Köder-Substrat diente (bisher) ein knetbares Gemisch aus gesiebtem lehmigem Schluff (aus dem Ap-Horizont einer Löß-Schwarzerde bei Bad Lauchstädt, Bez. Halle) Weizenkleie-Pulver (Branflakes), Milch-Pulver, Gips, Mannit, Pepton und Wasser. Die Köder-Lamellen entstehen bei der Ausfüllung von Perforationen in dünnschichtigen, schmalen, als Lochstreifen bezeichneten Plaste-Streifen (Abb. 1).

Die am unteren Ende gefalzten Lochstreifen wurden mit Hilfe eines Bodenstechers (eines zweckentsprechend hergerichteten Messers) senkrecht in den Boden (das Substrat) gedrückt. Auf diese Weise waren die seriell angeordneten Lamellen in einem engen Spalt in verschiedener Tiefe der Fraßtätigkeit von Tieren ausgesetzt. Obwohl diese unvermeidlich künstlichen Versuchs-Bedingungen vermutlich die naturgegebenen Verhältnisse auf nicht einschätzbare Weise verzerrt haben, zeigen die vorgestellten Beispiels-Befunde (und unsere auf hunderten von Versuchen basierende Erfahrung), daß die anhand von Freßaktivitäten (Freßaktivitäts-Profilen) nachweisbare funktionelle Schichtung ein naturgesetzliches Charakteristikum für die raum-zeitlich variierenden Lebensbedingungen im untersuchten Boden (Substrat) sind.

Um Freßaktivitäts-Raten fehlerkritisch schätzen zu können, wurden zur Stichprobenerhebung jeweils mehrere Lochstreifen (in Gruppen) in Abständen von 12–20 cm so eingebracht, daß sich die jeweils obersten Lamellen dicht unter der Oberfläche befanden. Die Boden- oder Substratoberfläche ist, da die zootischen Aktivitäten in der Regel mit zunehmender Tiefe abnehmen, die Bezugsebene zur Ermittlung der funktionellen Strata. Nach bisherigen Erfahrungen mit dem Köderlamellen-Test kann das die Sproßbasis-Schicht (Interstitial-Horizont = L_i) die funktionelle Oberfläche dicht bewachsener Böden sein.

Die Zahl der zu einer Gruppe gehörigen Lochstreifen ergab sich jeweils aus der Anzahl der Lamellen pro Lochstreifen und damit der Zahl der in gleicher Ebene exponierten Lamellen. In der Regel wurden mindestens 4 Gruppen zur Prüfung einer Variante eingebracht, gelegentlich auch 8.

Je nach den hygro-thermischen Bedingungen wurden die Lochstreifen nach 4 oder mehreren Stunden bzw. einem oder mehreren Tagen ohne besondere Sorgfalt aus dem Boden gezogen und nach dem Abspülen von anhaftenden Schmutzpartikeln auf einem Leuchttisch begutachtet. Dabei war es in der Regel möglich, zwischen Fraßspuren und Artefakten zu unterscheiden (s. Abb. 3). Die binären Daten (0 oder 1) wurden elektronisch aufgenommen und als Reihen ihrer Summen (X- und Y-Files; s. Tabelle 1) in numerischer Reihenfolge gespeichert. Die biometrische Auswertung wurde (auf der Grundlage des U-Tests nach MANN & WHITNEY, 1947) mit Hilfe spezieller Computer-Programme durchgeführt.

Mit Hilfe von Köder-Tests können systematisch verschiedene Freßaktivitäts-Raten sowohl an untersuchten Orten (auch eng benachbarten Struktur-Elementen sonst gleicher Flächen) als auch in (morphologisch differenzierten wie undifferenzierten) Schichten festgestellt werden. Nachweisbare vertikale Aktivitäts-Unterschiede variieren je nach den herrschenden hygrothermischen Bedingungen (und deren mutmaßlichem Einfluß auf die metabolischen Prozesse) und sind schon deshalb nur als „funktionelle Schichten" zu deuten. Die morphologisch ausgeprägten Schichten und Schichtgrenzen in Böden naturbelassener Standorte sind jedenfalls funktionell nicht streng determiniert; sie sind als Ergebnisse von stochastisch häufigen Prozessen nur als Regelzustände zu verstehen.

Köder-Tests (insbesondere vereinfachte Verfahren; TÖRNE, 1990) können für system-ökologische Übersichtsuntersuchungen von edaphischen Prozessen nutzbringend angewandt werden.

[Оценка пищевой активности почвообитающих животных с помощью ламина-теста]

На примере отобранных результатов описывается скрининг-тест, характеризующийся тем, что (спустя несколько часов или дней после начала эксперимента) на тонких пластинках с приманкой можно увидеть следы питания животных. Этот в принципе простой метод предназначен для того, чтобы при относительно небольших затратах труда, простым способом и рационально получить большее число данных, пригодных для статистической обработки.

В качестве приманочного субстрата служила мягкая смесь из просеянной горшечной глины (из горизонта A_p лессово-черноземной почвы вблизи Бад Лаухштедт, округ Галле), молотых пшеничных отрубей, порошкового молока, гипса, маннита, пептона и воды. Пластинки с приманкой получали путем заполнения этой смесью перфораций в тонкослойных узких пластмассовых полосках, так называемых чипсах (рис. 1).

Зафальцованные на нижнем конце пластмассовые полоски или «чипсы» вдавливались с помощью специально изготовленного ножа вертикально в почву (субстрат). Таким образом, серийно расположенные на различной глубине в узкой почвенной щели пластинки с приманкой доступны почвенным животным. Несмотря на то, что неизбежные в таком случае искусственные условия эксперимента по всей вероятности искажают природные условия и эти искажения не поддаются оценке, приведенные примеры и факты (и наш собственный опыт, основанный на сотнях экспериментов) показывают, что выявляющееся на основе пищевой активности функциональное распределение является характерной чертой изменяющихся пространственно-временных условий жизни в исследуемой почве (субстрате), обусловленной природными законами.

Для того, чтобы критически с точки зрения возможных ошибок оценить нормы питания животных, для взятия выборочных проб также использовали в соответствии с условиями несколько полосок (базовых групп), расположенных на растоянии 12–20 см друг от друга так, чтобы смотря по обстоятельствам верхние пластинки находились в непосредственной близости от поверхности почвы.

Поскольку с глубиной зоотическая активность падает, то поверхность почвы или субстрата является исходным параметром для установления функционального слоя. По этой причине пластмассовые полоски или чипсы следует вносить в почву с большой осторожностью, не нарушая при этом структуру поверхности почвы (в том числе и находящейся на ней растительности).

По прежним опытам с ламина-тестом функциональным может быть слой прорастния побегов – интерстициальный горизонт L_1 в почвах с густой растительностью.

Число полосок (чипсов), относящихся к одной базовой группе, определялось числом пластинок (с приманкой) на одной полоске и, следовательно, и числом пластинок, экспонированных на одном уровне. Как правило, для проверки одного варианта использовались не менее 4 групп, иногда и 8 базовых групп.

В зависимости от гидротермических условий спустя 4 и более часов или через один или несколько дней пластмассовые полоски уже без особой предосторожности вынимались из почвы, освобождались путем промывания от приставших к ним частичек грязи и просматривались на освещенном предметном столике. При этом, как правило, можно было отличить следы питания животных от артефактов (см. рис. 3). Бинарные данные (0 или 1) регистрировались электронным методом и как ряды их сумм (x- и y-ряды; см. табл. 1) накапливались в нумерической последовательности. Биометрическая оценка проводилась на основе U-теста по Манну и Уитни (Mann & Whitney) с помощью специальной компьютерной программы.

Применяя ламина-тесты, можно установить систематически различные нормы пищевой активности животных как в исследуемых местообитаниях (и в тесно примыкающих структурных элементах в остальном подобных площадей), так и в слоях почвы (морфологически дифференцированных и недифференцированных).

Прослеживаемые различия в пищевой активности животных по вертикали варьировали в зависимости от господствующих гигротермических условий (и их предположительного влияния на метаболические процессы), и уже на этом основании могли рассматриваться только как функциональные слои.

Морфологически выраженные слои и их границы в почвах естественных местообитаний во всяком случае функционально строго не дифференцированы, их следует понимать как результат стохастически множественных процессов только как регулируемых состояний.

Ламина-тесты могут с пользой применяться и при нынешнем уровне развития метода для системно-экологических исследований эдафических процессов.

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8. References

ADLER, G., 1987. Zur mesoklimatischen Kennzeichnung landwirtschaftlich genutzter Standorte von Pflanzenbaubetrieben. Z. Meteorol. **37**, 291–298.

Anonymous, 1969. Ergebnisse der forstlichen Standortserkundung im Staatlichen Forstwirtschaftsbetrieb Eberswalde. Herausgeber (ed.): VEB Forstprojektierung Potsdam. 274 pp.

BABEL, U., 1972. Moderprofile in Wäldern. Stuttgart. 120 pp.

DUNGER, W., & J. FIEDLER, 1989. Methoden der Bodenbiologie. Jena 432 pp.

HARRISON, A. F., P. M. LATTER & D. W. H. WALTON, 1988. Cotton strip assay: an index of decomposition in soils (ITE symposium no. 24). Institute of Terrestrial Ecology. Merlewood Research Station Grange-over-Sands, Cumbria, U. K. 176 pp.

HEATH, G. W., C. A. EDWARDS & M. K. ARNOLD, 1964. Some methods for assessing the activity of soil animals in breakdown of leaves. Pedobiologia **6**, 80–87.

– M. K. ARNOLD & C. A. EDWARDS, 1966. Studies in leaf litter breakdown. I. Breakdown rates of leaves of different species. Pedobiologia **6**, 1–12.

LIEBEROTH, I., 1981. Zuordnungsrahmen zwischen den Einheiten der DDR-Bodenklassifikation und den Einheiten der neuen FAO/UNESCO-Weltbodenkarte. Arch. Acker- u. Pflanzenbau **25**, 9, 513–517.

LAVELLE, P., & B. PASHANASI, 1989. Soil macrofauna and land management in Peruvian Amazonia (Yurimaguas, Loreto). Pedobiologia **33**, 283–291.

MANN, H. B., & D. R. WHITNEY, 1947. On a test whether one of two random variables is stochastically larger than the other. Ann. Math. Statist. **18**, 50.

SEASTEDT, T. R., 1984. The role of microarthropods in decomposition and mineralization processes. Ann. Rev. Entomol. **29**, 26–46.

SZEGI, J., 1988. Cellulose decomposition and soil fertility. Budapest. 186 pp.

TÖRNE, E. VON, 1978. Experimenteller Nachweis zootischer Einflüsse auf den Stoffumsatz in einem Kiefernforst. Pedobiologia **18**, 398–414.

– 1989. Schätzung von Freßaktivitäten. *In:* W. DUNGER & H. FIEDLER (eds.). Jena. 255–260 pp.

– 1990. Schätzungen von Freßaktivitäten bodenlebender Tiere. II. Mini-Köder-Tests. Pedobiologia **34**, fasc. 4 (see Abstr. on p. 101).

Synopsis: *Original scientific paper*

TÖRNE, E. VON, 1990. Assessing feeding activities of soil-living animals. I. Bait-lamina-tests (1). Pedobiologia **34**, 89–101.

A new test for screening indefinite feeding activities of soil-living animals is described. This method is characterized by exposure of thin laminae of an artificial bait substrate to animals' feeding activities. Thin, narrow perforated plastic strips served as support for bait-laminae. The strips, each bearing a row of (usually) 16 lamellae (5 mm apart), were inserted as a group of 16 strips into the soil or soil cover (in rows or in a grid of ca. 40 cm × 60 cm). Depending on hygro-thermic and trophic conditions, which result in variable zootic activity, the strips were sampled after an exposure of some hours or some days and then examined on a light screen to assess feeding traces which were recorded as binary data (0 or 1). Sums of positive observations (numbers of pierced bait-laminae) from individual strips (S_x) and from each position on 16 strips of a group (S_y) were stored subsequently on a disk as alternating x- and y-sections of a file (a named row of data from a test). X-sections were subjected to the non-parametric U-test to estimate differences between sites, treatments etc., y-sections were used to estimate statistically differences of vertical strata.

A detailed description of methodology, preparation and application of strips and sampling is provided. The usefulness of bait-laminae-tests is exemplified by selected results. The main conclusions drawn from these results are:

In principle, comparative investigations on indefinite animal feeding activities are useful in determining the effects of any factors (or treatments) influencing processes within soil-ecosystems.

The short term bait-tests are of value in providing indicative data concerning edaphic processes. Results of screening tests can provide a fundamental orientation needed for complex ecological research.

Key words: Bait-test, bait-laminae, animal feeding activity, visual assessment, screening, biomonitoring, soil, functional layers, geophaga, humiphaga, microphytophaga.

Abstract: *Preliminary note*

TÖRNE, E. VON, 1990. Schätzungen von Freßaktivitäten bodenlebender Tiere. II. Mini-Köder-Tests [Assessing feeding activities of soil-living animals. II. Mini-bait-tests]. Pedobiologia **34**, fasc. 4.

Details are given of some modifications of the bait-lamina-test described previously. Unlike tests with laminated baits, thicker supports with dried baits are inserted into the soil with the result that baits are not affected by shrinkage or friction as in the previous method.

Two types of plastic supports with lines of perforations were used: (1) Strips, 1 mm thick with one line perforation, 2.5 – 1.5 – 2.5 mm in diameter (funnel-like on both sites), distance of perforations 5 mm. (2) Round sticks, 5 mm thick, with two orthogonal lines of funnel-like perforations, 5.0 – 2.4 – 5.0 mm in diameter, distance of perforations 10 mm.

Exceptionally disks (1.5 mm thick, with a circle of 12 funnel-like perforations 2.0 – 1.5 mm in diameter, distance of holes 5 mm) were used for preference-tests with *Porcellio scaber* LATR.

The bait consisted of pulberized cellulose, bran flakes, leaves of *Urtica dioica* or *Calamagrostis epigejos* mixed to a soft paste pressed into the holes in the bait holder. A modified motor of a sewing-machine was used to rotate sticks to facilitate filling with the bait.

Used supports were roughly cleaned by short-term exposure to compost containing dense populations of *Eisenia fetida* (SAVIGNY) and then washed in clear water.

Various supports and different bait materials were tested to simplify procedures and application of the method.

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